NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20034

SURVEY OF THERMOCLINES AND DRAG-REDUCTION PROPERTIES OF WATER IN THE MAJOR BASINS AT THE NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

by

N. Santelli

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SHIP PERFORMANCE DEPARTMENT
RESEARCH AND DEVELOPMENT REPORT

November 1973

Report 4089

SURVEY OF THERMOCLINES AND DRAG-REDUCTION PROPERTIES OF WATER IN THE MAJOR BASINS AT
THE NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

The Naval Ship Research and Development Center is a U. S. Navy center for laboratory effort directed at achieving improved sea and air vehicles. It was formed in March 1967 by merging the David Taylor Model Basin at Carderock, Maryland with the Marine Engineering Laboratory at Annapolis, Maryland.

Naval Ship Research and Development Center
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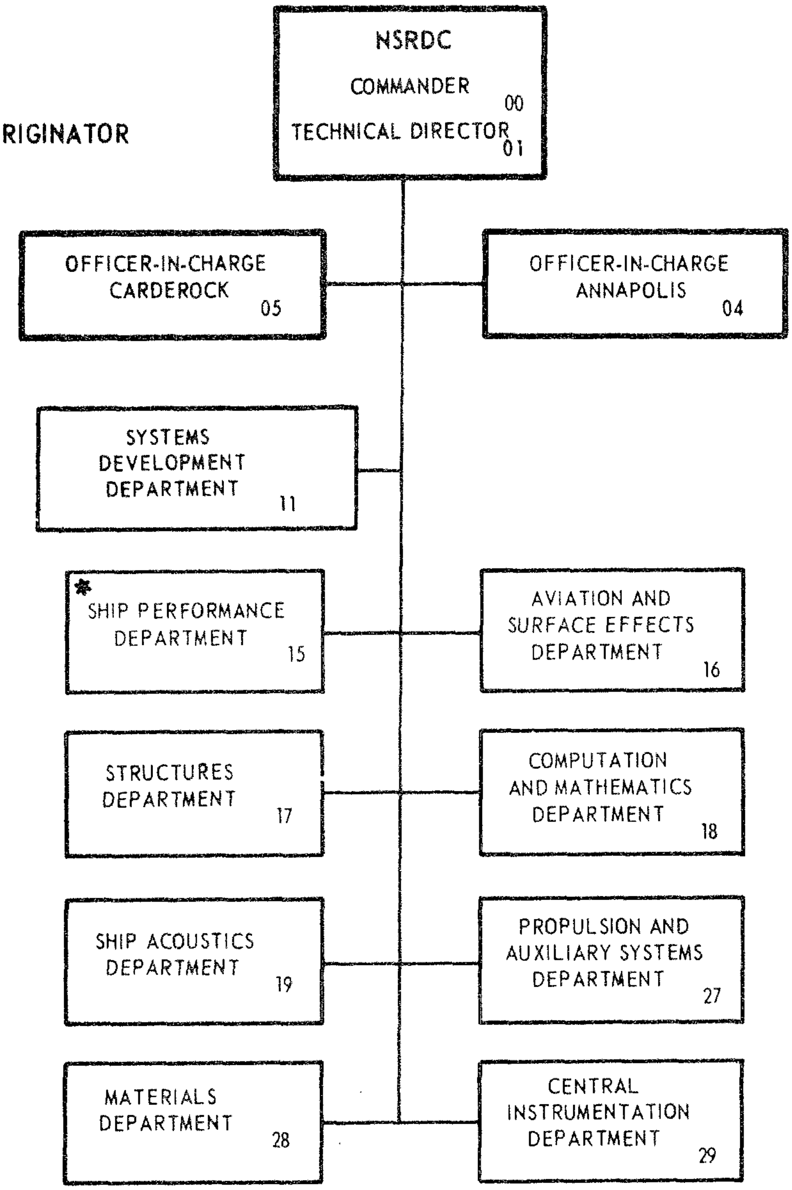

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DEPARTMENT OF THE NAVY
NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER
BETHESDA, MARYLAND 20034

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ABSTRACT

A systematic survey of temperature variation with depth was conducted in the David W. Taylor Model Basin (TMB) and the Maneuvering and Seakeeping (MASK) facilities at the Naval Ship Research and Development Center. Water samples from the basins were periodically tested for the presence of drag-reducing substances. A significant upper thermocline and an overall temperature gradient were found in the two basins of TMB. A weak, transient gradient was found in the seakeeping basin of MASK. No significant gradient could be found in the rotating-arm basin of MASK. Except for two highly transient occurrences in the drydock area of the rotating arm, none of the samples from the basins exhibited significantly lower drag. A tendency for slightly lower drag, 1 percent or less, was noted in the TMB basins. Precautions that are taken at the Center to prevent buildup of drag-reducing substances in the experimental facilities appear to be highly effective. It is possible that, with proper simulation techniques, several interesting stratified-flow phenomena can be studied, using existing facilities.

ADMINISTRATIVE INFORMATION

This work was authorized under the Naval Ship Systems Command Exploratory Development Program and was funded under Task Area SF43421007, Task 01712, Work Unit 1520-100.

INTRODUCTION

Both routine and sophisticated experiments in towing basins may be affected in an important way by periodic variations in the ambient temperature distribution and the presence of drag-reducing molecules. The water in the basins at the Naval Ship Research and Development Center (the Center) has never been systematically "calibrated," and it has been difficult to assess the effect of basin environments on test results. A year-long temperature survey of the major facilities at the Center was undertaken. In conjunction with the survey, a periodic check was made for the presence of drag-reducing substances in the waters of the various Center facilities.

In recent years, there has been increasing interest in stratified flow in the oceans. The possibility of using existing facilities to study this phenomenon has intrigued several investigators. Preliminary data about the vertical distribution of temperature are necessary to make a decision concerning the feasibility of using Center facilities to investigate the hydrodynamics of bodies in or near a thermocline.

Hoyt[1] and Barnaby and Dorey[2] have suggested that random discrepancies in drag tests of a given model may be due to unnoticed algae blooms. Care is taken to prevent algae growth at Center facilities through filtration, skimming the surface, unofficial introduction of algae-eating fish, and keeping interior lighting to a minimum. However, the water in the basins has never been systematically checked for the presence of naturally occurring drag-reducing substances.

The David W. Taylor Model Basin (TMB) and the Harold E. Saunders Maneuvering and Seakeeping Facilities (MASK) are the major water basins at the Center.[3] The TMB consists of both a deep-water and a high-speed basin. The deep-water basin is 22 feet deep, 51 feet wide, and 3078 feet long. It is divided into two separate channels, west and east, with a J-shaped turning area 10 feet in depth forming the western end. The high-speed basin is 21 feet wide, 2968 feet long, 10 feet deep for one-third of its length, and 16 feet deep for the remaining length.

The MASK or Saunders facility also consists of two basins. The round rotating-arm basin is 260 feet in diameter and 21 feet deep. The rectangular seakeeping basin is 240 feet wide, 360 feet long, and 20 feet deep; at one end it contains a deep water channel 50 feet wide, 322 feet long, and 35 feet deep.

This report contains the results of a year-long temperature survey and a search for the presence of drag-reducing substances. It describes the apparatus and procedures used in the survey, presents the temperature profiles obtained, draws conclusions concerning the significance of the temperature profiles found, and presents the results of the drag-reduction measurements. The rotating-arm basin was excluded from the full survey but some limited data taken at this facility are presented.

EXPERIMENTAL APPARATUS AND PROCEDURES

A thermocouple was used to measure the temperature of the water at various depths. Fifty feet of cable connected the thermocouple to a galvanometer. The cable, which also provides thermocouple support, was strung through a pulley attachment at one end of a 12-foot aluminum pole. A takeup reel for the cable was attached at the opposite end. This "fishing pole" apparatus allowed measurements to be taken several feet from the sides of the basins as well as from the towing carriages.

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[1]Hoyt, J.W., "The Influence of Polymer-Secreting Organisms on Fluid Friction and Cavitation," Naval Ordnance Test Station publication 4364, pp. 1–8 (1967).

[2]Barnaby, K.C., and A.L. Dorey, "A Towing Tank Storm," Royal Institution of Naval Architects, Proceedings, Vol. 107, p. 265 (1965).

[3]Vincent, M. da C., "The Naval Ship Research and Development Center," NSRDC Report 3039, pp. 10–18 (1970).

Between September 1971 and October 1972, temperature measurements were taken at 2- to 3-week intervals in the Taylor Model Basin and at somewhat longer intervals in the seakeeping basin of the Saunders facility. Limited time allowed only two comprehensive temperature surveys and three limited spot checks of the rotating-arm basin.

A rotating-disk rheometer was used to check for the presence of naturally occurring, drag-reducing substances in the water. The particular apparatus used has been described by Huang and Santelli.[4] Samples of water were periodically taken from the various basins. These samples were compared in the rheometer to samples of distilled water at the same temperature. When a particular sample showed evidence of containing drag-reducing substances, larger samples were taken and were subjected to a comprehensive series of tests. When the sample showed the same resisting torque as the distilled water, it was discarded. The water samples were usually taken at or very near the surface. Occasionally samples were taken at lower depths for comparison.

In addition certain water samples were allowed to stand in direct sunlight for 3 days, following which, the samples were evaluated, and the results were compared with samples tested immediately after being drawn.

GENERAL SURVEY OF TEMPERATURE DATA

Temperature measurements were begun in the Taylor Model Basin in September 1971. Tables 1 through 5 in Appendix A give the date and location of each temperature survey, as well as the value of the vertical temperature gradient dT/dz near the surface. The various factors of possible influence upon dT/dz are also listed. Each point in the table represents the average of several measurements taken along the length and breadth of a particular facility on a given day.

Figure 1 shows the average and extreme values of the profiles encountered in the low-speed basins. From the onset of the survey a definite temperature variation with depth was found. This gradient was reasonably uniform across the width of the basin and varied only slightly along the length. Continued experiments showed this gradient varied with usage of the basins. During extended periods of continuous use, 5 days or longer, such as during submerged submarine-model experiments, the temperature gradient goes to zero. After such a thorough mixing of the water, the temperature gradient reforms slowly. At least 36 hours are required, and even after 72 hours the gradient may not be reestablished. Occasionally, short duration tests of only 1 or 2 days are undertaken. If such an experiment is of a surface model, only the upper thermocline is disturbed, and the gradient generally reforms a few hours after the test is completed.

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[4]Huang, T.T. and N. Santelli, "Drag Reduction and Degradation of Dilute Polymer Solutions in Turbulent Pipe Flows," NSRDC Report 3678 (1972).

In the Taylor Model Basin, the temperature gradient also varies with weather conditions through the year, especially during the winter months. As the weather becomes colder, complicating factors arise. The first is that the heaters located at intervals along the side walls of the basin walkway cause local heating at the water surface. Warm airblasts from the heaters, which are 15 feet from the outer edge of the basins, have a considerable effect on the upper thermocline. The same is true of cold air draughts from open doors. Figure 2 shows typical variations encountered. Apart from the local "hot and cold spots," the average water temperature was lower at the eastern end of the basin throughout the year. The difference was very slight during the summer. As a result, noticeable variations of the vertical temperature profile with length occurred only during the colder months.

The high-speed basin exhibited a temperature profile similar to that of the low-speed basin. Average and extreme values of the gradients found in the deep and shallow portions of the basin are given in Figures 3a and 3b. "Hot and cold spot" variations are similarly present. The high-speed and the low-speed basins are equipped with a common water-filtration system. The water intakes and outlets of the filtration system appear to have only a limited, localized effect on the overall temperature gradient.

As previously mentioned only two complete surveys were taken at the rotating-arm basin of the Saunders facility. The first survey was taken while the filtration system was in operation; the second was accomplished 2 days after the system was shut down. As seen in Figure 4, no significant variation of temperature with depth could be detected while the filtration system was in operation. Only a slight variation was detected while the filtration system was in operation. This variation may have been the initial stage of the formation of a significant temperature gradient. However, subsequent measurements revealed no increase in the magnitude of the temperature gradient.

The seakeeping basin of the Saunders facility was surveyed during the summer and fall of 1972. Figure 5 shows the results of data taken during the initial measurements. A variation in temperature with depth is noticeable. The value of dT/dz in the upper thermocline, however, was only 0.15 degrees centigrade per meter. This is slightly higher than the lowest value found in the TMB basins. Throughout the remainder of the survey, except for the final measurements taken in October, no significant vertical temperature gradients could be found.

There are several possible factors or combinations of factors to account for these differences. Since any temperature gradient in the seakeeping basin would be destroyed during wavemaking activities, the thorough mixing caused by wavemaking may have prevented the formation of a significant gradient. Another possible factor came to the attention of the investigator after the completion of the survey. Virtually the entire bottom area of the TMB rests on bedrock. However during construction of the Saunders facility, a hollowed area in the underlying bedrock was discovered. This area was filled with concrete, and now forms a significant but unknown portion of the bed for the seakeeping basin. Since this slab reaches a thickness of 9 feet, considering that concrete generally exhibits a thermoconductivity only one-third that of granite, this slab could be another contributing factor in the large variance in temperature gradients between the Saunders and TMB facilities.

The filtration system for the Saunders facility is in operation a greater percentage of the time than it is in the TMB facility. Also, while the normal filtration rates of the two systems are roughly the same, 2700 gallons per minute, the TMB facility contains one-third more water than the Saunders facility. This plus the wide, open areas of the Saunders facility as compared to the long, narrow structure of the TMB facility may be a significant factor in reducing temperature gradients.

For the last set of data taken in the seakeeping basin, the filtration system was shut down, and no experiments had been run for 3 days. A special effort was made to extensively survey the 35-foot-deep channel. As can be seen in Figure 5, only a rudimentary profile had formed. Later in the day, wavemaking activity was begun, reducing the gradient to zero. During the remainder of the survey period the basin experienced rather heavy usage. No further variation of temperature with depth was found.

RESULTS OF POLYMER SURVEY

From January 1972 until October 1972, water samples were taken from the low- and high-speed channels of the Taylor Model Basin on a regular biweekly basis. Approximately 60 percent of the samples tested exhibited less resisting torque than did control samples of distilled water at the same temperature. Approximately 11 percent of the samples tested exhibited more resisting torque. In all cases the difference was 1 percent or less. The accuracy of the rotating-disk apparatus is generally considered to be ± 2 percent; therefore, differences found are not appreciable. The trend, however, may be significant.

No correlation between differences in resisting torque and any parameter, time of year, temperature, etc., could be found. In some cases, water samples were allowed to stand in direct sunlight for 3 days. Subsequent rotating-disk measurements indicated no change in resisting torque when compared to torque of the freshly drawn water.

Samples of water were taken from the Saunders facility at 3- to 4-week intervals. None of the samples taken from the seakeeping basin or the main body of the rotating-arm basin revealed discrepancies in torque readings greater than one-half percent. An approximately equal number of samples showed resistance at more than the mean value for distilled water as at less than the mean. The same cannot be said for the drydock area of the rotating-arm basin. On two widely separated occasions samples drawn from the drydock exhibited some drag reduction. The first recorded a 3-percent reduction; the second, almost 7 percent less drag than the control sample or the water in the adjacent rotating-arm basin. Both these phenomena were short lived, less than 24 hours. Attempts to definitively explain the two occurrences or to correlate them with other unusual occurrences have failed. However, many common substances such as certain plastics or cellulose particles in suspension will give some drag reduction. Therefore, considering the short duration of the phenomenon and the fact that the main body of the rotating-arm basin showed no drag reduction, it is possible that some contaminant was accidently or deliberately introduced into this area by a workman or an observer. This hypothesis is reinforced by recurring observation by the investigator of debris, paper and plastic cups, pieces of wood, etc., collecting in this area.

DISCUSSION AND CONCLUSIONS

A significant upper thermocline and overall vertical temperature gradient can develop in both the low- and high-speed basins of the Taylor Model Basin facility. Its existence and magnitude depend mainly upon the number and type of experiments being conducted; however, they also appear to be dependent upon climatic conditions. Very hot, humid weather appears to favor the formation of a strong gradient.

A similar temperature gradient could not be found in the rotating-arm basin of the Saunders facility. An upper thermocline and overall temperature gradient were found in the seakeeping basin of the Saunders facility but only for a limited time. The gradient was much smaller in magnitude than the one found in the TMB facility.

The reasons for the difference between the Taylor Model Basin and the Saunders facility are not fully understood. It is likely that the difference in physical dimensions, filtration rate, usage rate, and type of usage tend to discourage the formation of a significant temperature gradient in the seakeeping basin of the Saunders facility. The thick slab of concrete beneath part of the seakeeping basin may also be a factor.

It is unlikely that the accuracy of any model tests conducted at the Center are affected by the existence of the upper thermocline and overall temperature gradient.

Precautions taken at the Center to keep the water of the major facilities clean and free of drag-reducing substances appear to be highly effective. The two transient occurrences of drag reduction in the drydock area of the rotating-arm basin are not indicative of normal operations. A trend of about 1-percent drag reduction in the TMB basins was noted. This is less than the limit of experimental error of the apparatus and less than a nominal 2 percent limit of error in drag experiments on models. It should not have a noticeable effect on the accuracy of drag experiments.

Finding significant thermoclines in the Center basins may provide the basis for investigations of internal waves, wake collapse, and thermal plumes in a stratified fluid. The relatively large size of the basins would allow the study of the wake far downstream of submerged bodies. The maximum magnitude of the temperature gradient in the basins is much greater than that found in the oceans. However, by utilizing sophisticated modeling techniques and carefully controlled experiments it may be possible to successfully model full-scale stratified flow phenomena.

ACKNOWLEDGMENTS

The author is indebted to J. Lefevre for conducting some of the initial measurements and to J. H. McCarthy of the Center for suggesting the project. The author would also like to thank M. Chang for valuable discussions during the preparation of this report.

APPENDIX A

SUMMARIES OF RESULTS OF TEMPERATURE SURVEY

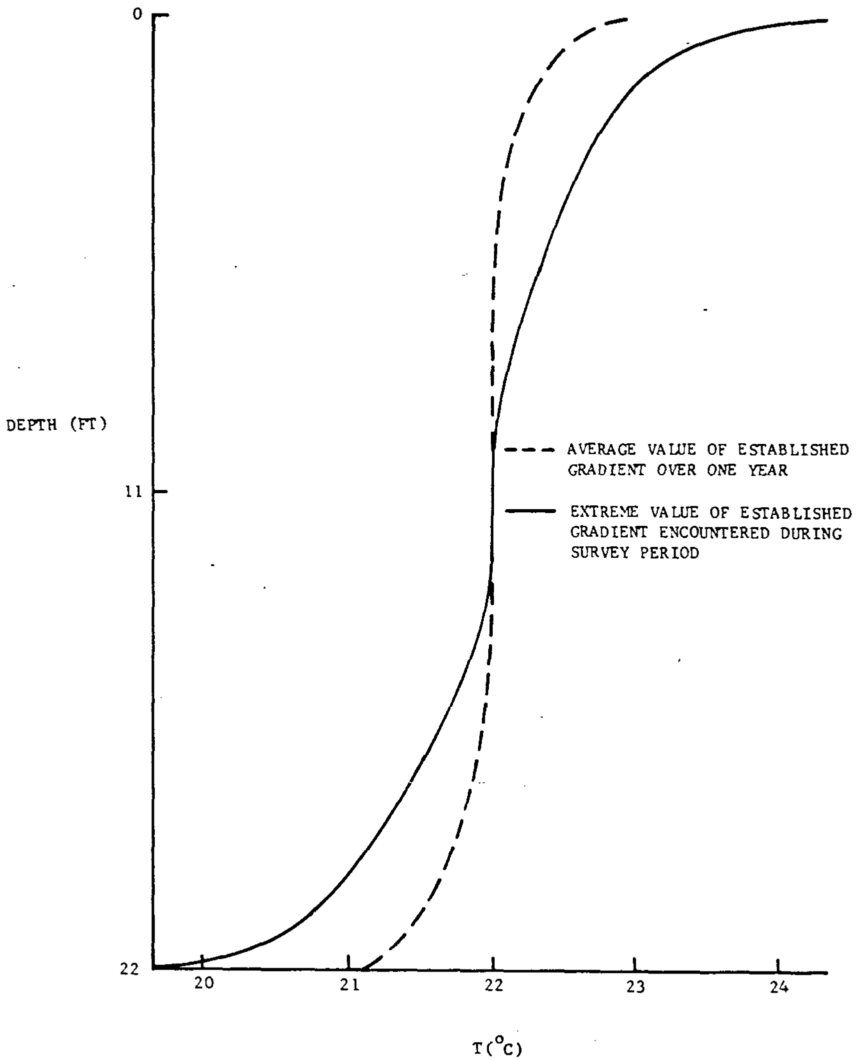

Figure 1 – Average and Extreme Values of Temperature versus Depth for Low-Speed Basin of Taylor Model Basin

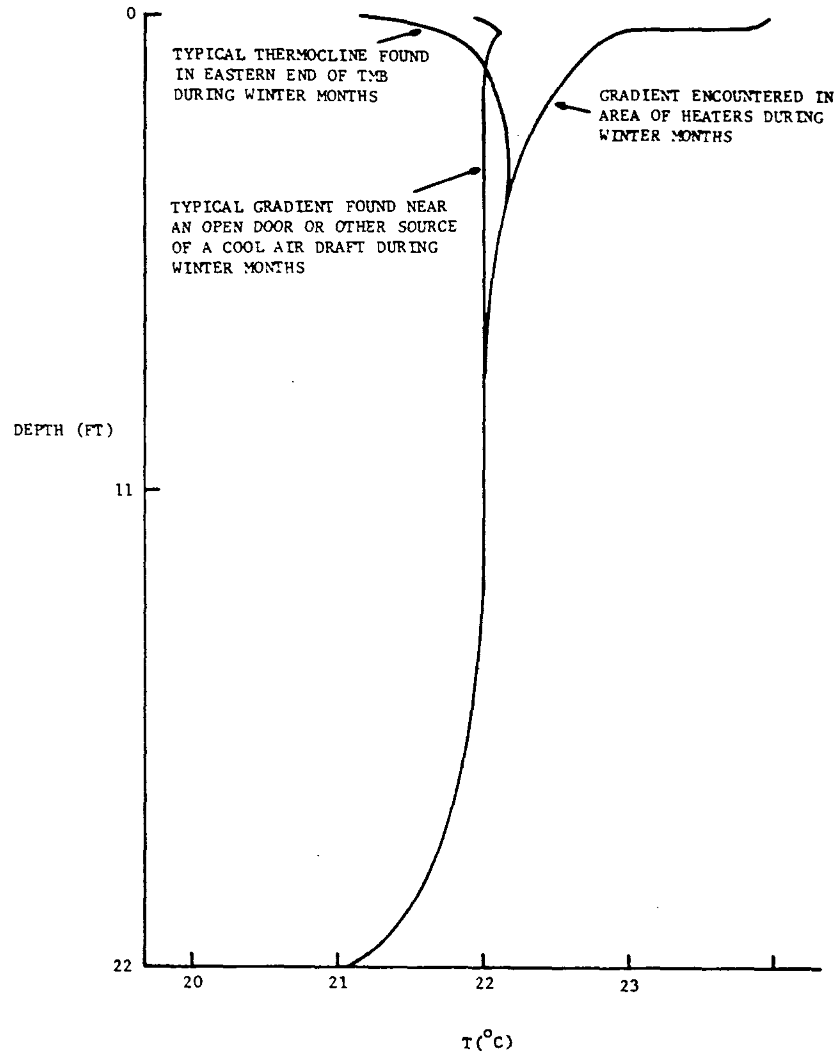

Figure 2 – Typical Anomalies of Temperature versus Depth for Low-Speed Basin of Taylor Model Basin

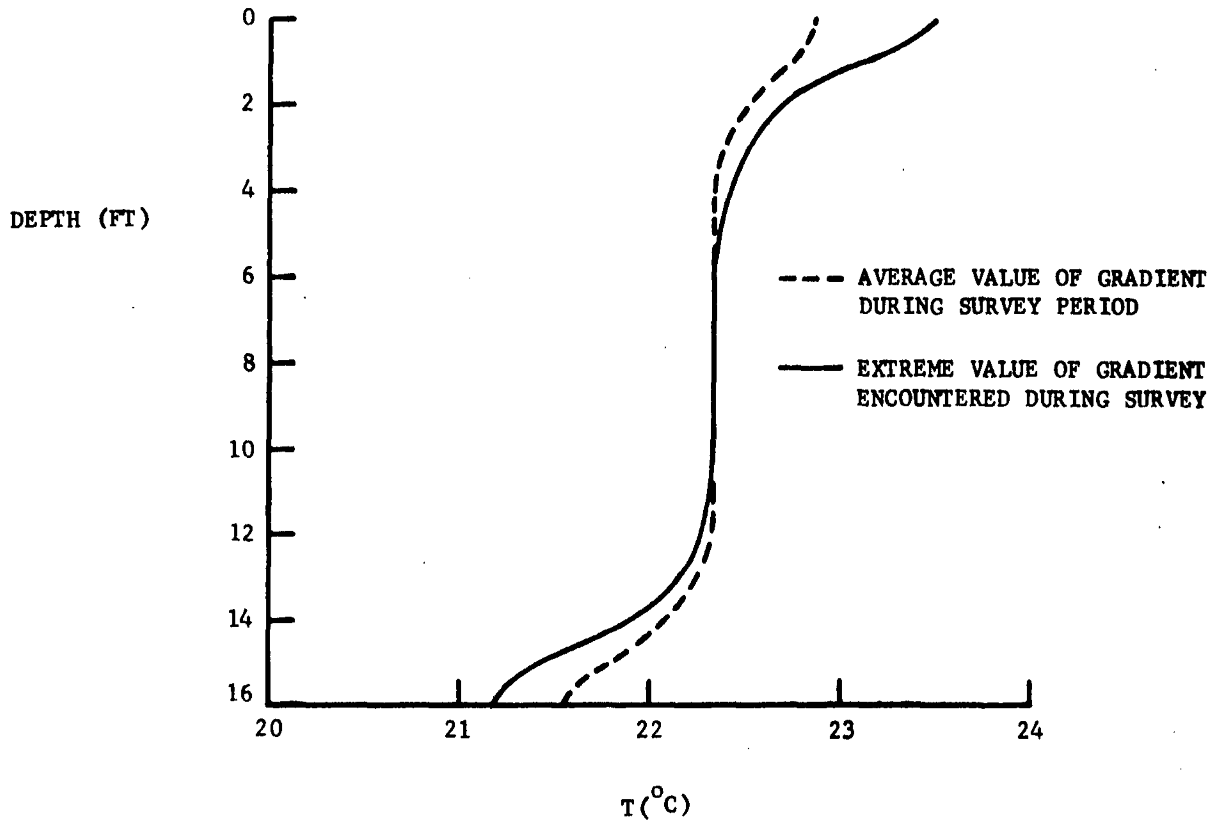

Figure 3a – For 16-Foot-Deep Section

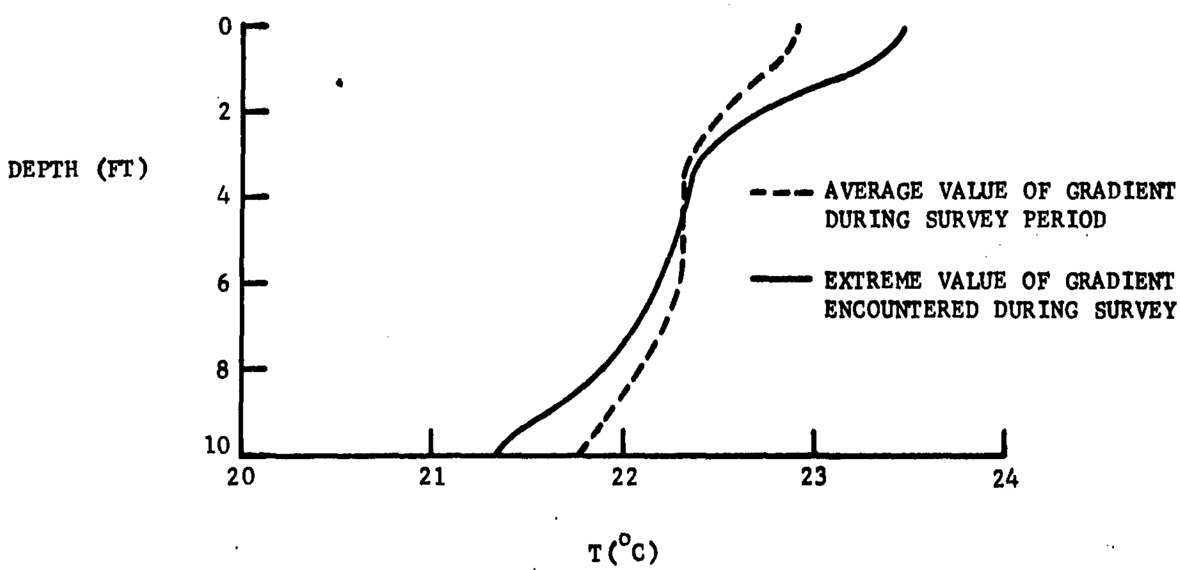

Figure 3b – For 10-Foot-Deep Section

Figure 3 – Average and Extreme Values of Temperature versus Depth for Various Sections of High-Speed Basin of Taylor Model Basin

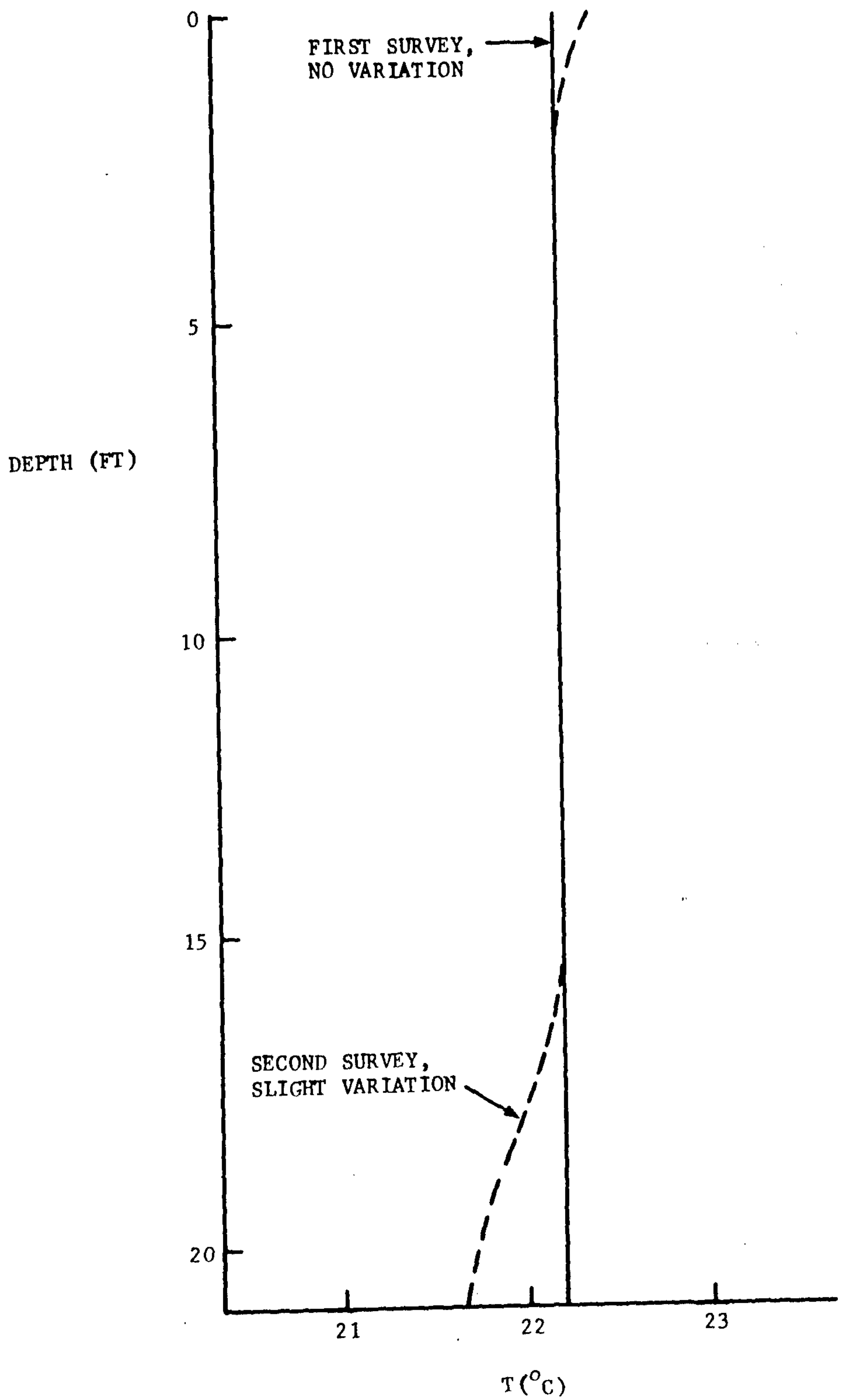

Figure 4 – Temperature versus Depth for the Rotating-Arm Basin of Maneuvering and Seakeeping Facility

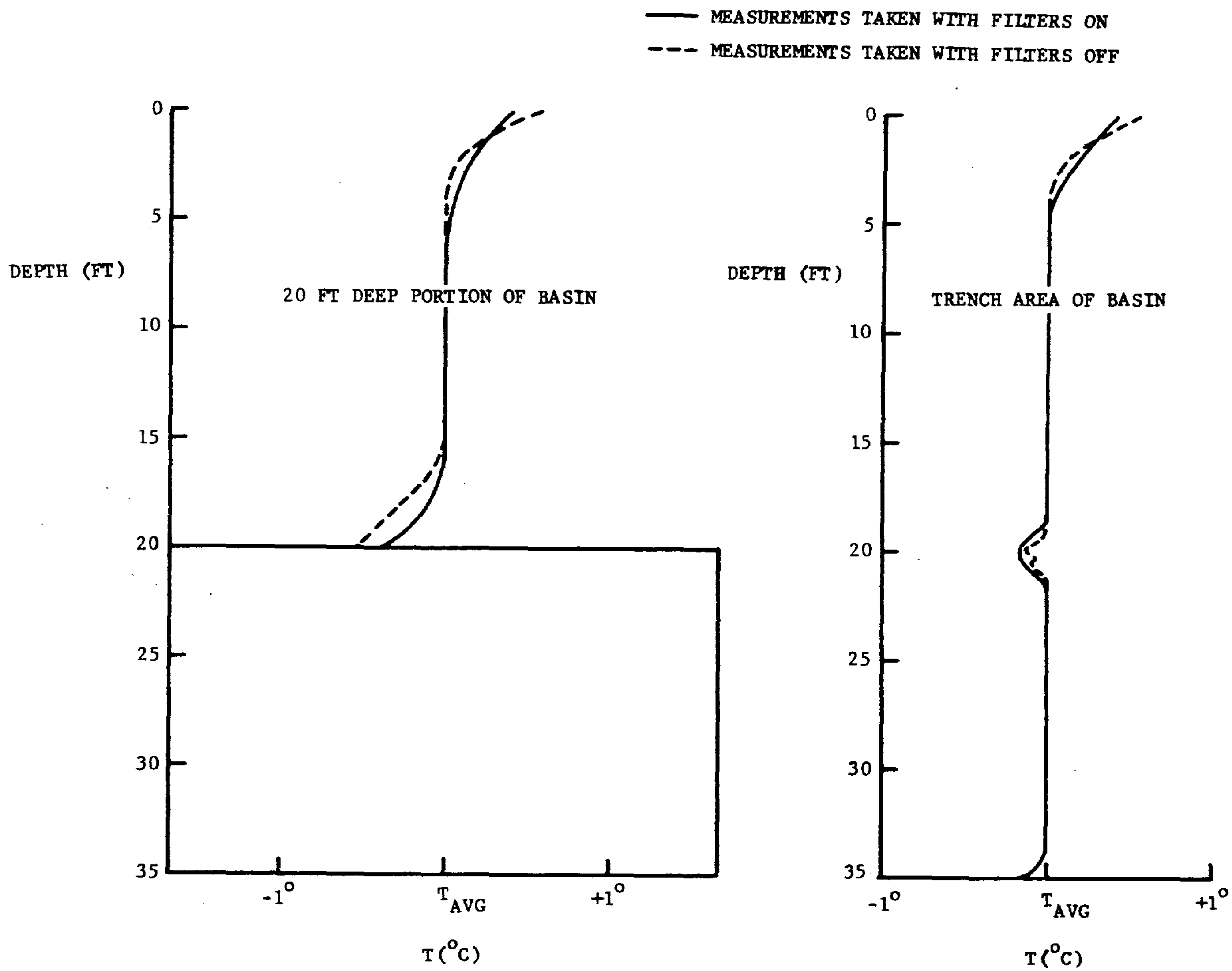

Figure 5 – Temperature versus Depth Values for the Seakeeping Basin of Maneuvering and Seakeeping Facility

TABLE 1 – TEMPERATURE SURVEY OF THE EASTERN CHANNEL OF LOW-SPEED BASIN OF TAYLOR MODEL BASIN

Test	Date	Air Temp. Inside, C	Outside Temp., C	Upper Thermocline dT/dz (C/m)	Total ΔT, C	Average T, C	Period of Quiescence	Remarks
1	10/27/71	25.2	27.0	0.78	2.15	23	5 days	Experiment in progress
2	11/8/71	22.8	21.8	0	0.4	23	0	
3	11/22/71	23.6	–	0.14	0.35	22.8	2 days	
4	12/6/71	21.8	–	0	0	21.6	0	Experiment in progress, submarine model
5	1/4/72	23.2	–	0	0.4	21.5	?	
6	2/28/72	21.0	10	0.12	0.42	20.6	at least 2 days	
7	3/14/72	–	6	0	0.2	20.4	0	Experiment in progress
8	4/4/72	20.5	9	0.42	1.1	21.1	3 days	
9	4/22/72	18.2	6	0.51	1.32	20.8	?	Experiment at western end only
10	5/6/72	–	16	0.55	1.66	21.0	at least 1 day	Water unusually calm
11	5/15/72	21.2	19	0.56	1.98	21.1	at least 2 days	
12	6/16/72	23.2	26.6	0	1.2	21.6	0	Surface experiment in progress; only upper thermocline disturbed
13	7/19/72	24.2	33.0	0.98	5.1	22.5	5 days	Extremely hot, humid day
14	8/4/72	24.8	30.0	0	0.1	22.8	0	Long, 24 hr a day test in progress
15	8/21/72	25.5	29.9	0.43	2.1	22.9	3 days	
16	9/5/72	23.5	26.0	0.44	2.3	23.0	3 days	
17	9/18/72	23.0	28.0	0.29	1.9	23.1	2 days	
18	9/29/72	22.8	25.0	0	0.5	23.0	0	Experiment in progress
19	10/14/72	22.8	23.0	0.68	3.0	23.1	7 days	

TABLE 2 — TEMPERATURE SURVEY OF THE WESTERN CHANNEL OF LOW-SPEED BASIN OF TAYLOR MODEL BASIN

Test	Date	Air Temp. Inside, C	Outside Temp., C	Upper Thermocline dT/dz (C/m)	Total ΔT, C	Average T, C	Period of Quiescence	Remarks
1	11/8/71	22.8	21.8	0	1.4	23	2 days	No upper thermocline
2	11/22/71	23.6	—	0	0.35	23.5	0	Experiment in progress
3	12/6/71	21.8	—	0	0	22.3	0	Experiment in progress
4	1/4/72	23.2	—	0.2	1.15	21.8	?	
5	2/28/72	21.0	10	0.19	2.0	21	3 days	
6	3/14/72	—	6	0.1	1.3	20.8	?	
7	4/4/72	20.5	9	0.54	2.9	21.3	several days	Water level 36 in. low
8	4/22/72	23.2	6	0.68	2.2	21.1	?	
9	5/6/72	—	16	0.54	1.9	21.2	at least 1 day	Previous experiment in western end only
10	5/15/72	21.2	19	0.59	2.1	21.2	at least 3 days	Previous experiment in J-portion of basin only
11	6/5/72	21.5	22.2	0.34	1.65	21.3	at least 2 days	
12	6/16/72	23.8	26.6	0.19	0.9	21.9	?	
13	7/17/72	26.0	33.3	0.43	1.7	22.3	2 days	
14	7/19/72	25.1	33.0	1.21	5.5	22.5	2 days	Very hot, humid day
15	8/9/72	25.9	31.0	0.59	2.9	22.9	4 days	
16	8/11/72	26.0	31.5	0.43	2.5	23.0	3 days	
17	9/5/72	23.5	28	0.39	2.1	23.1	3 days	
18	9/27/72	22.8	27	0.39	2.4	23.3	4 days	

TABLE 3 – TEMPERATURE SURVEY OF THE HIGH-SPEED BASIN OF TAYLOR MODEL BASIN

Test	Date	Air Temp. Inside, C	Outside Temp., C	Upper Thermocline dT/dz (C/m)	Total ΔT, C	Average T, C	Period of Quiescence	Remarks
1	9/9/71	27.5	29.4	0.656	2.13	24.5	?	
2	10/14/71	23.2	24.0	0	0.4	23.0	0	Experiment in progress
3	10/27/71	25.2	–	0.81	2.9	23.2	?	
4	11/8/71	24.9	21.8	0.49	2.0	24.8	?	Filters off
5	11/22/71	23.8	–	0.1	0.5	23.5	14 days	Filters on
6	12/6/71	21.8	–	0	0.1	21	7 days	Filters on
7	1/4/72	23.2	–	0.24	0.75	21.4	?	
8	21/28/72	21.0	10	0	0	21	0	Experiment in progress
9	3/14/72	–	6	0.25	0.89	20.6	10 days	
10	4/22/72	23.2	6	0.09	0.25	21.2	1 day	Filters off
11	5/6/72	–	16	0.65	2	22.0	8 days	Filters on
12	6/16/72	24.9	–	0	0.9	22.5	a few hours	Experiment just completed
13	7/22/72	29.4	30.5	0	0.8	23.4	0	Experiment in progress
14	8/7/72	29.1	31.5	0.2	1	24.1	48 hours	
15	8/30/72	–	29.8	0.69	2.2	24.4	?	Filters off
16	9/18/72	26.1	25.1	0.48	2.0	24.4	at least 2 days	

TABLE 4 – TEMPERATURE SURVEY OF THE SEAKEEPING BASIN OF THE MANEUVERING AND SEAKEEPING FACILITY

Test	Date	Air Temp. Inside, C	Outside Temp., C	Upper Thermocline dT/dz (C/m)	Total ΔT, C	Average T, C	Period of Quiescence	Remarks
1	3/6/72	22.7	–	0.15	0.6	20.9	10 days	Filters on during survey
2	3/21/72	22.2	17.2	0	0	20.6	3 days	Filters on
3	4/11/72	21.6	19.4	0.1	0.5	20.5	23 days	Filters on
4	5/1/72	21.9	20.5	0	0.2	20.9	2 days	
5	5/22/72	22.0	21.0	0	0	20.9	0	Wavemaking experiment in progress
6	7/17/72	25.9	33.3	0	0.1	21.8	2 days	Filters on
7	8/4/72	24.8	29.9	0	0.1	22.1	1 day	Filters on
8	9/11/72	23.9	28.8	0	0.1	22.4	2 days	Filters on
9	10/4/72	21.6	21.1	0	0.2	22.6	1 day	Filters off; taken during break in wavemaking experiment
10	11/25/72	21.5	20.0	0.19	0.6	22.0	3 days	Filters off for 3 days before survey

TABLE 5 – TEMPERATURE SURVEY OF THE ROTATING-ARM BASIN OF THE MANEUVERING AND SEAKEEPING FACILITY

Test	Date	Air Temp. Inside, C	Outside Temp., C	Upper Thermocline dT/dz (C/m)	Total ΔT, C	Average T, C	Period of Quiescence	Remarks
1	5/19/72	22.7	–	0	0	21.5	19 days	Filters on
2*	6/20/72	22.8	27.1	0	0	22.0	49 days	Filters on
3*	8/4/72	27.1	31.6	0	0	22.2	11 days	Filters on
4*	9/11/72	26.8	28.8	0	0	22.4	40 days	Filters on
5	10/4/72	23.0	22.8	0.13	0.6	22.8	74 days	Filters off for 2 days prior to survey

*Indicate spot checks of temperature, rather than complete survey.

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13. ABSTRACT

A systematic survey of temperature variation with depth was conducted in the David W. Taylor Model Basin (TMB) and the Maneuvering and Seakeeping (MASK) facilities at the Naval Ship Research and Development Center. Water samples from the basins were periodically tested for the presence of drag-reducing substances. A significant upper thermocline and an overall temperature gradient were found in the two basins of TMB. A weak, transient gradient was found in the seakeeping basin of MASK. No significant gradient could be found in the rotating-arm basin of MASK. Except for two highly transient occurrences in the drydock area of the rotating arm, none of the samples from the basins exhibited significantly lower drag. A tendency for slightly lower drag, 1 percent or less, was noted in the TMB basins. Precautions that are taken at the Center to prevent buildup of drag-reducing substances in the experimental facilities appear to be highly effective. It is possible that. with proper simulation techniques, several interesting stratified-flow phenomena can be studied, using existing facilities.

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